SOLAR PASSIVE SYSTEMS

FOR BUILDINGS

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Solar Passive Systems for Buildings
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PREFACE

Today, a new architectural renaissance is taking place world over - the major thrust applied to the less intensive, more energy conscious building design.

"Solar Passive Systems for Buildings" is a survey of the design knowledge and provides a systematic presentation of proven concepts with suitable illustrations. It was developed by reviewing, comparing and having professionally evaluated current design literature to provide a compact overview of the knowledge that lies behind the familiar sets of building practices. It does not however recommend the technical decisions that might be made in actual design process.

This document is intended as a general guide to stimulate the imagination of architects, designers and other building practitioners who are likely to be called upon to contribute substantially to the energy starved world of tomorrow.

CONTENTS

INTRODUCTION

In primeval times, man sought shelter in rock caves and these were manifestly the early form of human dwellings. Changing weather conditions, expanding occupation in agriculture and growing population altered early man's shelter needs. Utilizing local materials, climate and changing conditions, an incredibly diverse number of structures were built: neolithic farmers who developed early rectangular wood frame-works from circular earth lodges; desert nomads with camel-packed goat-skin tents; the Australian aborigines with their underground shelters; the Dogon tribes of Timbuktu whose mud cities reflect their view of the cosmos. With suitable soil and climatic condition, caves have provided shelter for man and other animals throughout history. In addition to natural caves, there are numerous regions where people have carved their homes from the solid rock, often with spectacular results.

As early as 15000 B.C. migratory hunters in Europe had discovered that turfs and earth were excellent insulators. They buried the simple round hut in a shallow excavation, building up a wall of turfs about the framework. This primitive pithouse then became the source for the elaborate earth lodges of Europe, North America and Asia. More advanced traditional designs could be noticed in the archeological excavations at Harappa and Mohenjo-Daro and recent excavations at Kurukshetra, Nalanda and other places. Archeologists report that buildings revealed in these excavations belong to 3000 B.C. These buildings were found to have mud brick walls, which were quite massive, no openings on the northern side, and only nominal walls on the south and southeastern sides. The design of the buildings indicates the popularity of the courtyard-type design, which has now been accepted as an ideal design in regions of climatic extremes and large diurnal temperature variations. In winter, the massive mud brick walls would store incident solar energy and provide cooler temperatures in the rooms during the day. This energy was then used for providing warmth during the cold nights, thereby maintaining comfort conditions during both the day and night. During summer, the people would stay indoors where it would be comfortably cool during the days, and they would sleep on the flat roof tops during the nights.

Major conscious attempts in passive design in India were first demonstrated at the International Low-Cost Housing Exhibition held in 1954. These were later used for comfort by Central Building Research Institute (CBRI) in collaboration with National Building Organisation (NBO) (Ref. 49). A notable example at the exhibition was of "Growing House" designed by Mr. Harold Hay, which had a special design of Cap-cavi wall. Also, the experiment on moveable insulation was first tried in this house and it was this experience which later resulted into now famous "Sky Therm System". This was modelled in 1975 by Gupta (Ref. 19) and has recently been tested by CBRI, Roorkee and ASTRA group in Indian Institute of Science, Bangalore (Ref. 34). Some of the recent bold concepts have been developed in France, e.g. Trombe Model System. Early house built in 1950 or before often appear very traditional in design with seperate solar collecting systems except windows. Later, innovative designs including complete analysis and design procedures have been developed notably by Balcomb and his associates and by Shaw at MIT.

The use of natural systems for producing comfortable indoor conditions is a goal which is still being sought, two thousand years after the Iranians used it to great advantage and Greeks had enough confidence to codify them as below :

1. Face the south, where the sun spends the winter;
2. Keep the winter winds away by embankments or vegetation;
3. Shade against the summer sun;
4. Let cooling be done by evaporating water;
5. Work with, rather than against nature.

These concepts are of tremendous importance to India and possibly the only feasible answer economically - only our architects have to choose not to follow without discrimination.

SOLAR PASSIVE CONCEPTS

Overview

Solar passive design concepts involve methods of collecting, storing, distributing, and controlling thermal energy flow through the natural principles of heat transfer. They are operations which can be translated directly to the building vocabulary, implying that energy flow through a building can be manipulated by the building itself. In this sense, the building is an active participant in fulfilling its own needs for heating, cooling, and light.

In the same manner, solar passive design represents a similar attitude toward building. The flow of thermal energy becomes one in a series of criteria affecting the conceptual and physical development of a building. Presently in the design of a building, components and relationships are already perceived with varying simultaneous meanings. For example, a roof can shelter, generate space, allow light to penetrate interior space, structure or mechanical systems, and act as a volume of space, structure or form. All these considerations are potential determinants of what a roof does in a building. Energy consciousness will impose yet another basic consideration to the set of components and relationship that become buildings.

It is a matter of viewing all the activities surrounding the design of a building through an energy conscious framework of concern, and then making design decisions in terms of those concerns. New criteria can produce new design logic. Glass openings allow the entrance of light into a building, but can also collect the sun's heat (if properly oriented); walls not only generate space, they can potentially store heat (dependent upon materials and location); and the inter-relation of spaces in a building not only organize activities but influence the speed and direction of energy flow. Guided by this new set of concerns, the architect and builder can manipulate existing building components to produce a building which is also its own energy system. The resulting building not only meets programme criteria of function and budget, but thermally performs in accordance with its needs. Architectural design at this level significantly increases the complexity of the designer's decision making process.

To put in a nutshell, passive design is not a style of building, or a packaged technological system that can be plugged into any building type. It is determined by how a building works to store and give off heat from the sun, how it cools and provides ventilation. It is an attitude toward building that can employ various conceptual and physical principles of thermal dynamics, which are applied to a building's material and form as they react to land climate. These principles can be translated to become qualities inherent in the building's construction and operation. It represents a sophisticated response to the environment, a dynamic interaction that can allow a building to collect and secure energy in order to heat and cool itself. It produces a building that is more integrated into its physical context, and offers design potential in a challenge to the architectural and building professions.

General Definition

The most widely accepted definition of a solar passive heating and cooling system is one in which thermal energy flows through a building by natural means, enabling the system to function without external power. The operation of a passive system involves the control of the thermal energy flow and includes the ability to vary the timing or location of energy flow inside the building. Control of the system introduces a level of design sophistication which is required in order to achieve the system's operational efficiency.

Both passive heating and cooling systems and their control operations can be inherent in the building's construction and in the buildings organisation. An efficient solar passive building will show understanding of the cyclic properties of existing climatic forces on a daily and seasonal basis. The definition of a solar passive systems, then is determined by the dynamics of its operation rather than any static rules or any aesthetic image. This expresses a functionalist approach to architecture, in which the solar passive system is an intrinsic part of the building, and requires the designer to broaden his concept of the building.

Basic Concepts

Three basic solar passive concepts have been identified, each involving different relationships between the sun, the storage mass and the living space. There are then, a set of six solar passive building types which exemplify one of these three concepts.

In the direct gain passive concept (sun to living space to storage mass) solar radiation passes through the living space before being stored in the thermal mass for longer term heating. The direct gain building type then exemplifies this solar passive concept. In the second passive concept, indirect gain (sun to storage mass to living space) a storage mass collects and stores heat directly from the sun and then transfers heat to the living space. Three types of indirect gain solar buildings are identified: Mass Trombe, Water Trombe and Roof Pond. The third solar passive concept is identified as isolated gain (sun to collector space to storage mass to living space) and incorporates a collector-storage component separate from the primary living spaces. Solar radiation is collected in area separate from the building, for transfer to a storage mass or distribution to the living spaces. Two examples of this passive concepts are the Thermosiphon building type and the Sunspace building type. Several wall and window component systems also illustrate the isolated gain concept.

SOLAR PASSIVE HEATING

Direct Gain Building Systems

The direct gain concept is the most common solar passive building solution. The solar radiation is collected in the living space and then stored in a thermal storage mass. Thus the actual living space is directly heated by the sun and serves as a "live-in" collector (figure 1).

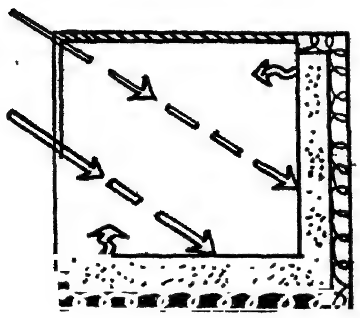


Figure 1

The basic requirements for the direct gain building type are : a large sun facing glazed (collector) area, with the living space exposed directly behind; a floor and/or wall storage mass of significant dimension for solar exposure and for capacity; and a method for isolating the storage from exterior climatic conditions.

Beyond these basic requirements there are a series of variations and controls that demonstrates alternatives in solar passive heating by direct gain. The most common variations are found in the location and the materials of the thermal storage mass. The best location of the storage mass is often decided by the physical laws governing natural heat flow by radiation and convection. For effective radiation distribution, physical proximity to the radiant body is an important factor in the location of the storage. Where convective air movements are caused by warm air rising, different temperature stratifications may also exist in a room, depending on the location of the storage mass. Typical location alternatives include : (a) the external building walls, (b) the internal walls, (c) the floor surface, and (d) free standing masses. In addition to storage location, there are significant variation in the storage materials which provide different heat capacities and different time lag properties. Storage materials vary from concrete, brick, sand, and ceramics, to water and other liquids, either singly or in various combinations, all radiating heat to the living space.

To add to the efficiency and the usefulness of direct gain and other passive systems, several controls must be considered. To prevent unwanted heat gain, sunshading is required for the large expanse of the sun facing glass.

Exhausts and vents will also help cool interior spaces when summer temperatures are high. To prevent unwanted heat loss, insulation for the glazed collector area is necessary to improve the resistance to heat transfer (U Value) of glass. Movable insulation panels, curtains, shutters etc., all work effectively to prevent unwanted heat losses on sunless winter days and nights and will also prevent thermal heat gain on hot summer days.

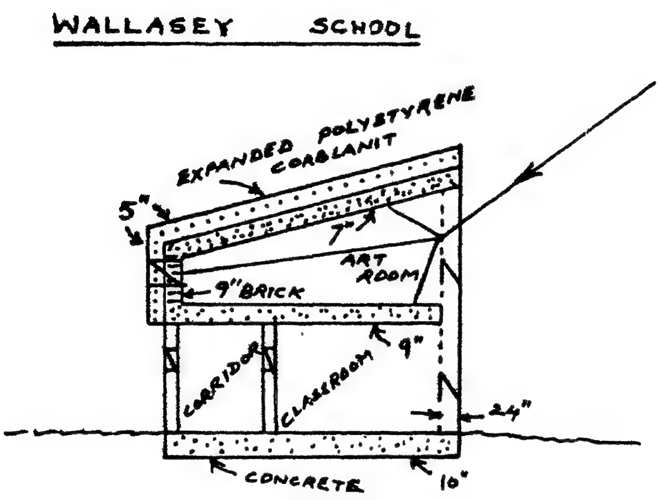


Figure 2

Example 1

Wallasey School, (figure 2) is one of the largest solar passive heated structure in the world, built in 1962. It is a large building of concrete construction with 17.5 to 25 cm of concrete forming the roof, the back wall, the floor and side walls with 12.5 cm of expanded polystyrene as the insulation outside. The solar wall is an expanse of glass, 7 m tall and about 80 m long, facing south. There are two sheets of glass, the one on the outside is clear and about 6 m inside of that is a diffusing layer of glass. It is a figured glass, so called, which refracts the suns rays, so that it irradiates the roof and the floor fairly uniformly. This structure is heated to about 50% by the sun, the remaining energy for heating the building comes from the lighting and from the students. The auxiliary system which was originally installed has not been needed. The school is located in Liverpool, England near the sea at a latitude of 53° north.

Indirect Gain Building Systems

In this system, the building continues to collect and store solar energy, but the sun's rays do not travel through the living space to reach the storage mass. This eliminates the direct gain temperature limitation whereby solar collection temperatures are limited by occupant comfort needs. Thus in the indirect gain concept, a storage mass collects and stores heat directly from the sun and then transfers heat to the living space.

Mass Trombe Wall

The first indirect gain solar passive building type is the Mass Trombe Wall, in which the sun's rays are intercepted directly behind the collector glazing by a massive wall which serves as heat storage (figure 3).

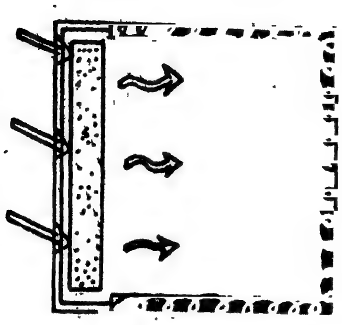


Figure 3

The required elements of the Mass Trombe building type involve only a large glazed collector area and a storage mass directly behind it. The range of storage materials identified in the existing mass trombe solar passive buildings includes concrete, adobe, stone, and composites of brick, block and sand. The property to consider while deciding on storage construction is the method of distribution inherent in the mass, with different heat storage capacities and emission properties. Radiant distribution from a storage mass to a living space can be almost immediate, or it can be delayed up to twelve hours, depending on the depth and time lag property of the storage material chosen. Distribution of air by natural convection is also viable with the mass trombe system since the volume of air in the intervening space between glazing and the storage of mass is being heated to high temperatures and seeks constant means of escape.

Through openings or vents at the top of the storage mass, hot air forces itself into the living space, drawing cooler room air through lower vents back into the collector air space. If the vents are controllable dampers, convective heat distribution can be shut off or started at will. Insulation placed between the storage mass and the living space can eliminate any direct radiation to the space, which controls distribution most effectively, but limits maximum thermal contribution. Distribution to and through the space, as well as storage construction, are variables which influence the mass trombe's system's efficiency in operation.

As in the direct gain building type, controls for the operation of the mass trombe type are important, though less crucial since the living space is not directly influenced by solar gain. For optimum efficiency in the winter, external movable insulation, or other insulation alternatives, should be included to protect the storage mass from wasteful heat loss to the overcast or night sky. In summer, unwanted

heating of the storage mass should be prevented by shading the glazed area with overhangs, by closing the external insulation, or by external dampers and vents. A mass trombe wall has the potential to provide induced ventilation for summer cooling of the living space, by including exhaust vents at the top of the glazed area. Solar heated air in the air space will force its way outside, drawing air from the living space to replace it. Therefore, another opening must be provided within the living space for replacing air - preferably from a shaded or cooler area. This continual air movement exhausts hot air from the building drawing in cooler air for ventilation.

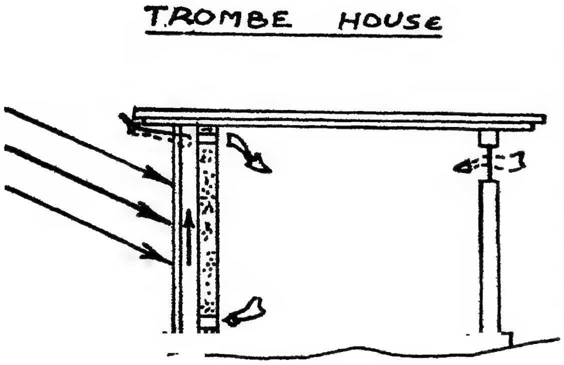


Figure 4

Example 2

A well known implementation of the storage wall concept is the Trombe house in Odeillo, France (figure 4) in which the wall is concrete. In the houses that were built in 1967 the wall is about 0.7 m thick. The primary mechanism for heating the house is by radiation and convection from the face of the wall with the thermal energy diffusing through this thick wall. About 30% of the energy is by a thermocirculation path which operates during the day only by natural convection with ports at the bottom and top.

Water Trombe Wall

The second indirect gain solar passive building type is identified as the Water Trombe Wall (figure 5) in which the sun's rays are intercepted beyond the collector glazing by a water storage mass, then converted into heat and distributed by convection and radiation to the living space.

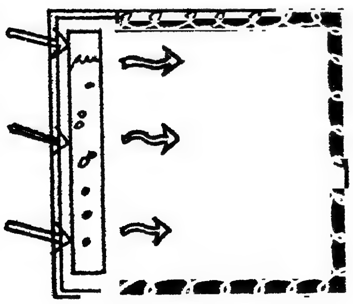


Figure 5

The water trombe wall involves the same principles as the mass trombe wall, but employs a different storage material and different methods of containing that material. These variations offer a variety of methods for the integration of the Trombe solar passive concepts into the building vocabulary.

The requirements for the water trombe wall are again a large glazed area and an adjacent massive heat storage. However, the storage is now water, or another liquid, contained in a variety of

Example 4

Harold Hay house (figure 8) is an example of roof pond. A system of insulating panels on the roof is used which slide back and forth on tracks. The water bags are left exposed to the sky during the day in the winter and during the night in the summer. This provides heat input in the winter and heat loss on a summer night. The insulation is put in place during a winter night to conserve heat and during a summer day in order to exclude the sun which is reflected from the top of the white panels. This system has worked very well and has operated without any auxilary, providing good thermal comfort in a small building.

Isolated Gain Building Systems

In the isolated gain solar passive concept, solar collection and storage are thermally isolated from the living spaces of the building. This concept is contrasted with the direct gain solar passive concept where the collection and storage are integral with the living spaces, and the indirect gain concept where collection and storage are separate from the living spaces, but directly linked thermally. The isolated gain concept thus allows collector and storage to function somewhat independently of the building, while the building can draw from them as its thermal requirements dictate.

Sunspace Isolated Gain

The sunspace isolated gain passive building type collects solar radiation in a secondary space which is separate from the living space, and also stores heat for later distribution (figure 9).

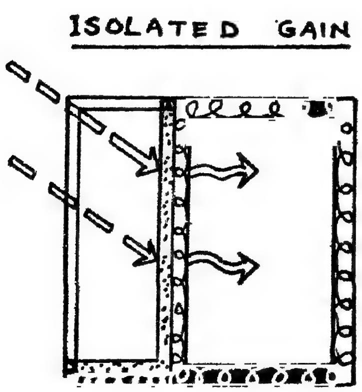


Figure 9

This 'Sunspace' offers both the potential separation of the collector-storage system from the living space, or the direct gain "live-in" situation which maximizes the use of low temperature solar gain. Thus, in concept, a sunspace solar passive system is midway between a direct gain system, in which the living space is the collector of heat, and a mass or water trombe system, which collects heat indirectly for the living space. Greenhouse represents a potential example of a 'Sunspace'.

The requirements for a sunspace solar passive building type is on the glazed 'collector' space which must be both attached yet distinct from the living space. Provided with a strong southern exposure, the collector space must be thermally linked to a solar storage mass for heat retention and later distribution.

The sunspace can be variable in its spatial and functional relationships to the primary living spaces of the building. It may vary from a minimum addition to a building with one small contact surface, to extending the entire south side of the building to being contained within the building with an interface on several sides. The specific location of the sunspace will depend on the building design, spatial organization, and sun orientation. A storage mass is also necessary in the sunspace type to retain heat for non-sunshine hours. Massive floors, walls, benches, rock beds, and covered pools of water can all provide effective solar heat storage; and could also be placed within reach of the winter sun for additional heat storage. If the sunspace is to additionally serve as a greenhouse for growing plants, the temperature restrictions set for the direct gain type for comfortable living condition would be re-established for the sunspace type. Otherwise, the unoccupied sunspace can store temperatures equal to the capacity of its storage materials, providing a controllable heat supply for the adjacent living spaces. When temperatures within the sunspace are not too hot for comfortable "live-in" conditions, the sunspace could then be occupied for more efficient direct gain heating.

The most mandatory control consideration for this solar passive building type is the design of the link between the sunspace and the living space. The walls which interface a sunspace and living space require built-in flexibility in order that these spaces can be thermally connected and separated as desired. The kind of distribution: radiation, convection, or conduction will be determined by these interfaces, and differentiate the sunspace solar passive building type from the direct gain type. In addition, as in other solar passive building types, shading should be provided to prevent overheating of glazed spaces during the summer; and some form of movable insulation would prevent unnecessary heat losses on winter nights or cloudy days. Humidity control is also an important consideration to prevent moulding within the storage mass in the plant or water occupied sunspaces.

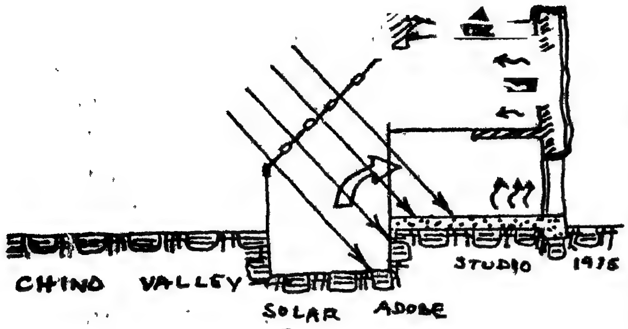


Figure 10

Example 5

Chino Valley Solar Adobe Studio - 1975
Chino Valley, Arizona, U.S.A.

The two story building (figure 10) contains about 51 sq.m. of living space and 14 sq.m. of greenhouse space. The walls are 30 cm adobe with 2.5 cm foam on the outer face (protected by 2 cm cement). The building includes a ground floor and loft space. The floor is a 10 cm concrete slab. The greenhouse is placed on the pit from which the adobe was dug, allowing its earthen floor to be below grade. The north wall has no window openings but there is a removable insulated panel on this face to facilitate entry of cars and equipment. Heat is collected from direct gain through 20 sq.m. of single glazed windows on a south facing greenhouse. Solar radiation strikes the greenhouse earthen floor, and the central part of the building. The heat is absorbed in the earth, the concrete floor, and the adobe walls where it is stored. Natural convection and radiation (facilitated by the below grade greenhouse floor) distributes heat through the house. The house maintains good air flow in response to the building's configuration. The rising heat hits the 45^o slope of the ceiling and bounces to the north wall, allowing heat to be absorbed at this end of the building. Domestic hot water is heated from active solar thermosiphoning collectors, which are located 3 meters away from the building. A vent at the top of the roof allows hot air to escape and creates a convection current through the house, facilitating cross ventilation. In the summer, the greenhouse area is covered with an awning made of snowfence. This shades the greenhouse and allows no direct heat gain inside the house. The adobe remains cool (insulation on the outer face inhibits heat gain from the exterior). Performance evaluation: 80% passive contribution with indoor temperatures ranging from 13-27^{o}C. Loft space is slightly over-heated during summer days. Openings should orient more southeast to take advantage of low morning sun. Auxiliary: Wood stove.

Thermosiphon

Use of the thermosiphon principle generates the sixth solar passive building type (figure 11). It includes a collector space which intercedes between the direct sun and the living space, and is distinct from the building structure.

THERMOSIPHON

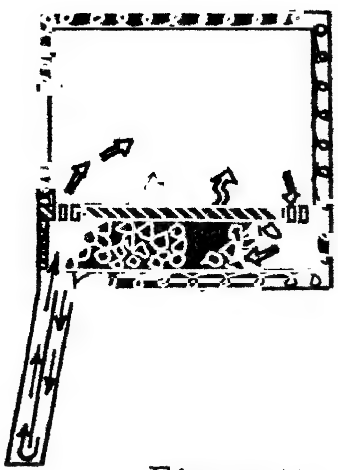


Figure 11

A thermosiphoning heat flow occurs when a cool air or liquid naturally falls to the lowest point (in this case below the collectors) and once heated by the sun, rises up into an appropriately placed living space or storage mass, causing somewhat cooler air or liquid to fall again, so a continuous heat gathering circulation is begun. Since the collector space is completely separate from the building space, the thermosiphon system begins to resemble the active systems. However, no external power from fans or blowers are needed to move the heat transfer medium. The thermosiphon principle has been applied in numerous solar domestic hot water systems, and offers equally great potential for space heating application.

The basic elements of the thermosiphon system include a collector space, usually a storage mass, and a method of distribution. Solar heat is collected on a dark metal or wood absorber surface, heating up the adjacent fluid, which then rises naturally into a storage mass for convective or radiant distribution. In the thermosiphon solar building type, the collector location is not fixed by the building and thus can take maximum advantage of sun exposure. Since the collector area is separate from the building facade, the house is also flexible in its wall and opening design. The solar storage mass can be located under the house floor, below windows, or in prefabricated wall elements. The storage location and material is the element of most variation and offers building and design flexibility. Distribution is provided by radiation from the storage mass and by convection (naturally rising air movements) from storage or directly from the collector, a variation which must be considered in the design stages. The spatial arrangement of the building is critical in providing effective heat distribution.

In the thermosiphon isolated gain building type, the link or contact area between the collector space and solar storage is not large, and can be easily blocked or disconnected to prevent air flow in adverse collector conditions (such as unwanted heat loss or overheating). However, controls must be carefully designed between the solar storage and the living space in order to meet the heating demands of the building and to prevent overheating.

The area of interface between the storage mass and the building will determine the speed with which the living space can be heated through radiation and convection. On the other hand, the greater the contact area between the storage and the living space, the more crucial is the control against untimely or overabundant space heating. For convective distribution from the storage mass of a thermosiphon solar passive building, controls similar to those used in the trombe building types are required, including operable dampers and insulation panels.

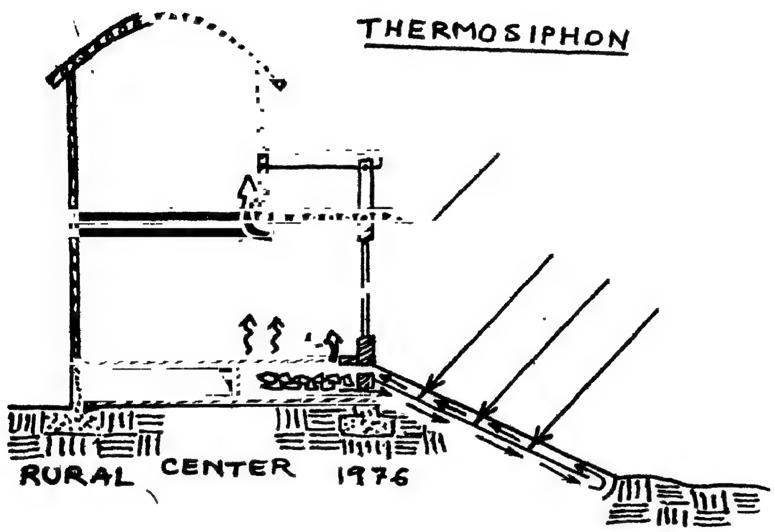


Figure 12

Example 6

The Rural Center - 1976
Northern, California U.S.A.

The Rural Center project (figure 12) includes 3 different passive systems designed into identical buildings for a comparison of solar prototypes. The 4 cabins were constructed of identical materials with an equivalent heat loss of 1250 KCals/Degreeday. Using low cost construction methods for reasons of economy, the cabins are of wood frame construction with insulation throughout. The barrel shaped roofs, with insulation, minimizes summer overheating. Window area has been minimized east and west, and eliminated on the north. This cabin employs a flat plate hot air collector to typify the sun-collector-mass-space passive system. 6.5 sq.m. of flat plate collector is located in front of the cabin, below the actual floor level. This location enables solar heat to transfer to the crawl space solar storage by natural convection. Cool-air from storage flows by gravity back to the collector for solar heating. This collector-storage method allows for the collection of high temperature heat of 49°C since the living space is not heated first. In addition to radiant heat from the floor slab, a fan helps distribute hot air from storage to the living space. 5.6 sq.m. of south facing glazing takes advantage of direct heat gain as well. By drawing cool night air into the rock storage at night, a lower temperature storage mass is provided for daytime cooling. 100% passive heating contribution with a 13°C minimum indoor design temperature. Climate, insolation and performance is being monitored. Auxiliary: None.

SOLAR PASSIVE COOLING

Solar cooling methods have been introduced in both the Trombe Wall and the Roof Pond solar passive heating systems. However, to outline in more detail some tested methods of cooling by the sun, five types of passive cooling are briefly defined :

Nocturnal Radiation

Briefly described in the roof pond solar passive building type, night sky radiation involves the cooling of a massive body of water or masonry, by exposure to a cool night sky. Although this depends on a large day-night temperature change, a clear night sky will act as a large heat sink to draw away the daytime heat, which has accumulated in the mass, until temperatures are equal to or cooler than the low night temperatures. During the day, this mass then acts as a "cold storage" to draw heat away from the living space, providing natural cooling.

Evaporative Cooling

When either moisture or bodies of water are present in an overheated. but somewhat dry climate, the sensible heat of air will be converted into latent heat in evaporating the water. Although the resulting formation of water vapor will increase the humidity of the air, it will also decrease the dry bulb temperature. The increase of humidity coupled with the decrease of sensible temperature combines to make the environment more comfortable. The spraying of the roof deck with water, or mechanical fans combined with water filters (evaporative coolers) are all examples of this natural cooling method.

Dessicant Cooling

On the other hand, the drying of very humid air can also provide natural cooling. Since high humidities prevent man from naturally cooling by sweating (the sweat will instead sit on the skin and not evaporate to cool the body), man's tolerance of higher temperatures is reduced. The dehumidiciation of air in the 23^{o}-27^{o}C range, intolerable at high relative humidities, will provide natural comfort at these temperatures. The use of dessicant salts, once easily available in the southeast, or ventilation, of mechanical dehumidifiers all represent methods of Dessicant Cooling.

Shape and Orientation : For a building with one primary axis of orientation, orientation of that axis towards the south will allow the controlled reduction of heat gain in warmer periods while enhancing heat gain in the cooler periods. More complex shapes will be more difficult to orient successfully. Square or round shapes will be more dominant axis of orientation require more detailed consideration in the designs of the building envelope and shading devices to respond effectively to variations in radiation intensities received by the different building surfaces. On a completely configured building, a detailed analysis of solar radiation on each surface, including self-shading. can assist orientation decisions. Because transparent surfaces transmit major amounts of radiation into the building, orientation should also be considered in terms of the type and construction of the building surfaces.

Wind

The regional microclimate wind patterns, such as velocity, frequency, and direction must be considered as they change throughout the year.

In overheated periods, wind can provide cooling of building surfaces and natural ventilation of building interiors. In sealed buildings, wind may cause unwanted infiltration. Wind exerts the greatest pressure when it is 90° to the surface of a building; at 45° the pressure is reduced about 50% (see figure 13). To increase the usefulness of natural ventilation in overheated periods, an orientation that accommodates wind conditions during those periods can be selected. Wind may enter a building anywhere between 45° and 90° to the building surface and still be effective. The precise angle which is most effective, however, is dependent upon the location of the openings which allow air to flow in and out.

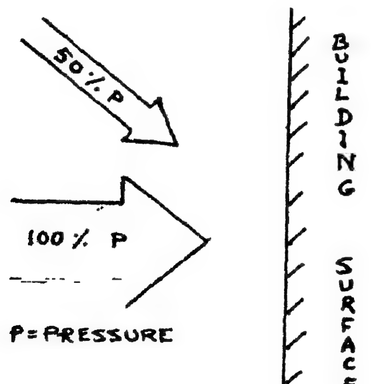
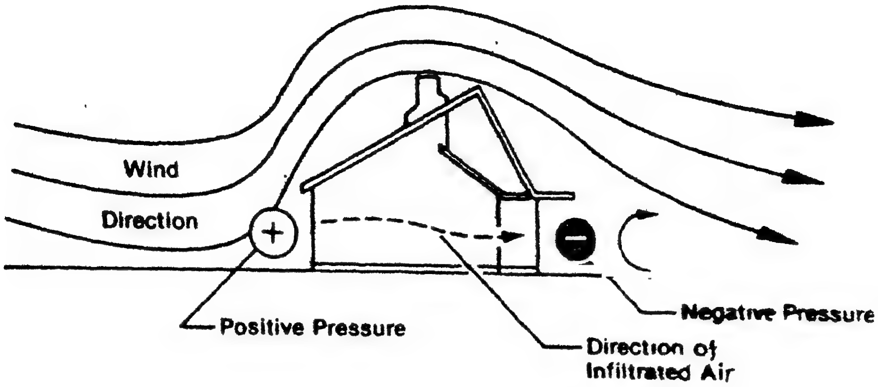


Figure 13

The pattern of wind flow around and through buildings depends on the buildings size, shape and orientation. When a stream of air interrupted by a building, the wind responds by flowing around and through the structure, eventually returning to its original flow pattern. Wind flow slows down as it approaches the building, creating a positive pressure on the windward face. As the wind is deflected around the corners, it speeds up and creates negative pressure zones on the ends and downwind (wake) side. (See figure 14).



WIND FLOW PATTERNS OVER HOUSE

Figure 14

As the height of a flat-roofed building increases, the amount of air going around the building increases while the air going over the building remains the same.

Climate

The major climatic elements important for the design of buildings are air temperature and humidity, solar radiation, wind and precipitation. Although these elements follow predictable regional patterns, they are constantly being modified by the influences of topography, objects in the landscape, large bodies of water and densely populated urban areas.

Temperature and Humidity

Using available local data; and the design tools mentioned below, it is possible to know the character of the local climate.

1. A yearly composite of the monthly 3-hourly average temperatures, when graphed would illustrate the overall temperature pattern of a locale. When this is done for an array of weather stations, the differences between regional climates would be strikingly apparent.

2. For a more specific local analysis, month by month graphs for a single weather station using the complete set of monthly, hourly or 3-hourly temperatures will help identify seasonally specific temperature design problems.

3. Line graphs can be developed to describe overall thermal variation for almost any desired time frame.

4. Overheated period charts identify those portions of the year when heat gain due to solar radiation should be maximised or minimised. To assemble this type of chart, hourly or 3-hourly temperature data for the year should be available. A quicker, but less precise, version could be assembled from monthly mean diurnal temperatures.

5. Degree-day comparisons are a convenient way of assessing the severity and the duration of the need for heating and cooling. A month-by-month inspection of daily degree-day accumulations gives a quantified overview of heating and cooling needs.

Solar Radiation

The following three variables enables to determine the angles of the building's surface in relation to the position of the sun :

1. Amount of incoming short-wave radiation (which varies as a function of the latitude);
2. Time of year; and
3. Time of day.

Calculations also require quantitative consideration of the three types of radiant heat transfer - direct short-wave radiation from the sun, diffuse short-wave radiation from the sky and diffuse short-wave radiation reflected from the surroundings. Finally, calculations of the amounts of available radiation will vary with changes in the cloudcover.

Graphic and tabulated calculations allow the position of the sun with respect to any building surface to be defined geometrically by the two solar angles - altitude and azimuth. Graphically, sun-path diagrams allow the designer to project the path of the sun across a three-dimensional "Sky vault" onto a two-dimensional horizontal plane. The sun path diagram allows a precise determination of the solar altitude and azimuth for any given time; this information provides the basis for later estimations of radiant heat gain in cool periods and sun-shading in warm periods.

Wind

Yearly, seasonal and daily wind patterns have to be studied. In underheated periods, analysis of average wind speeds and their prevailing directions may aid in design against infiltration and convective heat loss. In overheated periods, average summer wind speed and direction may be analysed for use of natural ventilation in summer cooling. If both seasonal and annual trends of wind velocities and direction are graphed, the resulting regional wind analysis will form a framework to which changes caused by microclimate variations at the site may be added.

Micro-Climate

Climate conditions on a specific site can vary substantially from available weather data, depending upon the altitude, vegetation and on the natural and man-made features on the terrain. These factors will, in many cases, modify the temperature, humidity, amount of radiation, and the direction and velocity of wind received at the exterior surfaces of a building. For many building projects, the designer has the means of reducing energy stress on buildings by taking into consideration these micro-climatic effects and by manipulating naturally occurring site features and the building location.

Temperature and Humidity

Surface air temperature is strongly affected by ground temperature, and ground temperature is a factor of the heat retention capacity of the soil. Within a given region, soil temperature below the depth of the surface effects, is a stable temperature throughout the year. This stable energy storage has great potential for climate moderation in buildings. Portions of buildings below grade will be cooled in summer by conductive heat loss, and warmed in the winter by minimizing contact with colder air temperature.

The degree to which the ground will moderate air temperature is dependent upon how each soil type manifests the following characteristics :

* Conductivity or the facility of the soil to absorb and/or radiate heat energy;
* Heat capacity or the ability of the soil type to retain the heat put into it;
* Albedos or surface reflectivity, the surface response of the soil to short-wave radiation.

In hot climates, some natural temperature reduction can be achieved by conductive heat loss through the floor slab or foundation. Soils with high conductivity characteristics will drain heat from the building into the cooler subsoil.

The presence of water on a site, or its introduction as a permanent fixture of the design, will have a moderating influence on temperature extremes.

Vegetation moderates climatic extremes. Trees, plants and grasses stabilise heat gain and loss patterns by :

1. Scattering incoming solar radiation;
2. Absorbing and storing energy in proportion to the water content of the vegetation and ground conditions created by vegetation;
3. Humidifying by transpiration;
4. Releasing stored energy as the ambient environmental temperatures decline;
5. Altering the surface form and reflectivity;
6. Shading the ground;
7. Modifying air movement; and
8. Trapping air insulation pockets.

The effects of vegetation could be seen in the figure 15.

EFFECTS OF VEGETATION

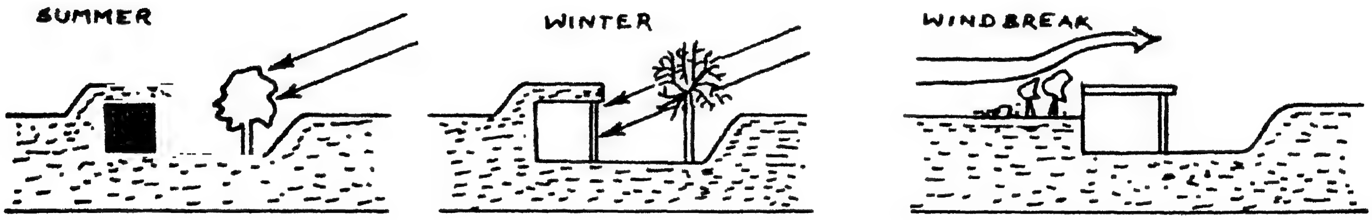


Figure 15

The cumulative effect of these factors shows vegetated areas to be cooler, more humid, and thermally more stable than un-vegetated areas. Due to humidification and interception of solar radiation, a vegetation covered ground surface and the air immediately above it are as much as 5°C cooler than unvegetated areas.

Solar Radiation

The orientation of ground slope will influence ground temperature and hence, air temperature. Sloped surfaces receive different amounts of radiation, depending on the orientation and inclination of the slope.

Generally, south-facing slopes receive lower amounts of radiation in overheated periods and the highest amounts of radiation in underheated periods. This is due to the higher solar altitude in the warmer period and to the lower, more southerly solar altitude in the cooler period. On the northern slopes, the landform itself can create shadows on the building in the underheated period when the sun's altitude is lower on the horizon. In addition, north slopes receive the lowest amounts of solar radiation in the cooler periods and comparatively low amounts of radiation in the warmer periods. East and west-facing slopes receive similar amounts of radiation. However, west-facing slopes receive the solar radiation at the time of peak diurnal air temperature, and the east-facing slopes receive it at the time of lower diurnal air temperature.

Vegetation can lessen the impact of radiation on a building in three ways :

* By absorbing varying amounts of direct or reflected radiation;
* By shading building surfaces from the direct radiation of the sun;
* By reflecting a portion of the radiation striking its surface.

In general, darker coloured, more coarsely textured vegetation will be most effective at absorbing and thereby reducing the quantity of radiation eventually striking a building's surface. Lighter coloured and smoother textured forms of vegetation will be less effective.

Wind

Like solar radiation, wind may have a significant impact on temperature. Basically wind causes convective heat losses and gains to building surfaces as well as to people inside when natural ventilation is used. Protecting buildings and people from convective wind effects will tend to make them warmer, not protecting them will do just the opposite.

Planting trees in front of a house structure on the windward side of a hill provides a short zone of protection while the same planting on the leeward will provide a long zone of protection for the same structure. Wind flow may be suddenly obstructed by a row of trees, or it may be guided more gradually over and around landscape features. Finally, trees will filter air flow, greatly reducing its velocity.

The actual changes of wind flow that occur on a building site are very difficult to predict. Not only do winds shift direction and change velocity, but vegetation changes in form and density over time as well. An understanding of how the physical characteristics of site barriers affect wind flow may, however, serve as guide for analysis. There are five primary variables :

1. Height : The greater the height, the greater the area of protection.
2. Density : The greater the density of windbreak, the greater wind turbulence will be behind the barrier.
3. Length : The longer a barrier is, the greater the velocity of air which sweeps around the ends.
4. Shape : An irregular rough windbreak is more effective in breaking up wind flow than one of uniform height.
5. Width : Width of a barrier is important only in terms of penetrability.

These characteristics of landscape barriers can be applied to building design in a variety of ways. An example of tree used as wind barrier may be seen in figure 16.

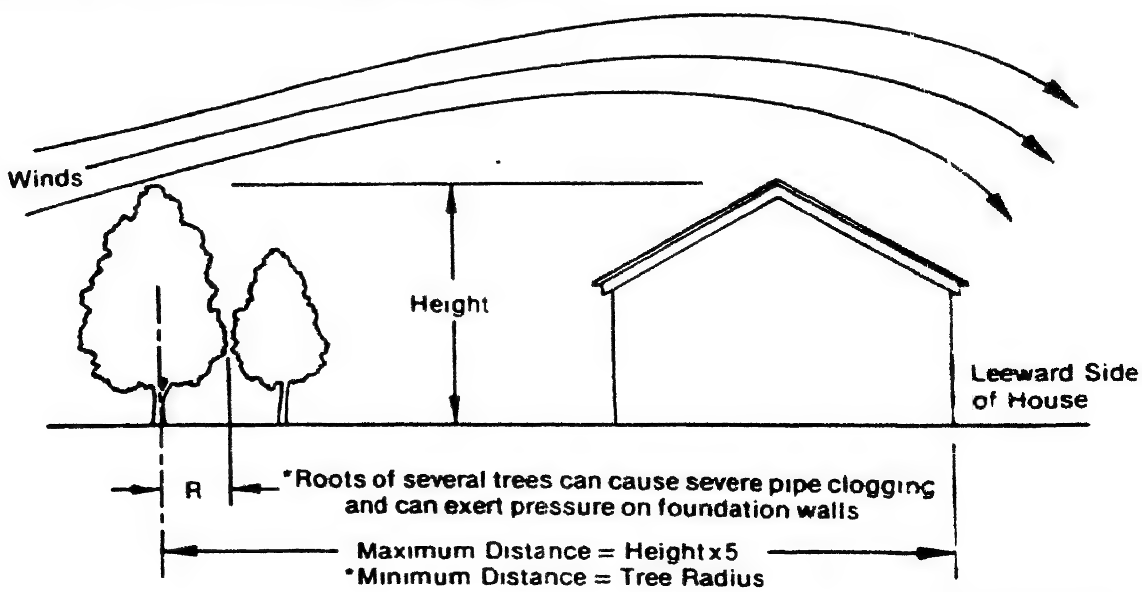


Figure 16

Form

The rate, direction, and magnitude of heat flow are moderated by building design. This heat-flow regulation is a product of building orientation, location, form and building materials. Some of the important form factors are as follows :

1. Building envelope
   - Size and shape
   - Surfaces
   - Insulation
   - Thermal mass
2. Glazing
3. Shading devices
4. Fenestration
5. Interior planning
6. Auxiliary comfort devices

Building Envelope

The boundary of the sheltering space is the building envelope and its performance requires it to :

* Restrict internal heat gain when external temperatures are high;
* Restrict internal heat loss when external temperatures are low;
* Dissipate excess internal heat gain caused by internal activities.

Size and Shape : An important consideration here is the surface to volume ratio (s/v). Buildings with less surface exposed to the natural elements (lower s/v) will be susceptible to radiate and conductive heat loss or gain, while the opposite is also true. Further, a large volume will possess a greater internal thermal inertia than a smaller volume of similar shape. Consequently, when there are large external temperature variations the larger volume will have more inertia to overcome and less surface area to be affected than a building that has a small volume.

If all external temperature stresses on a building were distributed uniformly over each exposure, then a building of square proportion would be ideal. However, stresses are not uniformly distributed. To increase winter heat gain and decrease summer heat gain, the south wall area should be larger than the east/west area.

Surfaces : When considering the effectiveness of radiant heat transfer, the material properties which will affect the energy flow are : absorbance, emissivity and reflectance. The emissivity and absorptivity of materials is dependent upon the particular wavelength of the incident radiation as well as the properties and temperature of the surface. In general, as the emissivity and absorptivity of a material increases, the reflectivity decreases. Solar radiation is short-wave, while radiation from earth-bound heated objects is long-wave. Building materials behave differently with respect to each radiation type. However, given any specific building material, it can be assumed that the absorptivity and emissivity are equal at the same temperature. The values for average emissivities, absorptivities, and reflectiveness of common building materials is shown in the table below :

Table : Average Emissivity, Absorptivity and Reflectivity of Some Common Building Materials

Surface	Emissivity/ Absorptivity low temp. radiation	Solar Radiation	Reflectivity
Aluminum, bright	0.05	0.20	0.80
Asphalt pavement	0.95	0.90	0.10
Brass/Copper, dull	0.20	0.60	0.40
Brass/Copper, bright	0.02	0.30	0.70
Brick, red rough	0.90	0.70	0.30
Concrete, uncolored	0.90	0.65	0.35
Glass	0.90	-	-
Paint, aluminum	0.55	0.50	0.50
Paint, white	0.90	0.30	0.70
Paint, brown, red green	0.90	0.90	0.10
Slate, dark	0.90	0.90	0.10
Steel, galvanized	0.25	0.55	0.45
Tiles, red clay	0.90	0.70	0.30

Insulation : The ideal insulator is that which permits the smallest energy flow per unit thickness and unit weight of the material. The material properties that a good insulating material will possess are basically a low factor of thermal conductivity and a low energy or heat capacity. Buildings with high internal heat gains may require a year-round heat balance analysis of external and internal heat gains and losses prior to determining the thickness of thermal insulation required to achieve maximum energy conservation.

Thermal Mass : The thermal mass of a building material is a measure of its energy, or heat capacity. The value of thermal mass is its ability to delay heat flow. Internal energy generated by people, lights and processes will first be absorbed by the building structure and building contents. The placement of insulation can have a great effect on the time lag of the composite wall. If, for instance, the insulation is placed on the outside, the time lag could be 13 hours. In a homogenous wall, the heat flow into and out is of an equal magnitude. But within a wall with an external insulation layer, the properties of heat flow become more selective.

Glazing

Glass surfaces transmit solar radiation directly and instantaneously into interior spaces. Reflective glass (glass coated with a thin metallic film) reflects a much larger portion of the incident radiation and is best used to prevent radiant heat gain in the overheated periods. It will also reduce heat gain in the under-heated period when such gain can be beneficial. Insulating glass can modify the amount of radiation transmitted into the interior substantially. The exterior pane should be selected for its heat reflecting characteristics and such a glass block can be used to reduce radiant heat gain to the interior by 35 to 75%.

Shading Devices

Solar heat gain through glass can be reduced by employing shading at the glass areas. Many different types of internal and external shading methods, techniques, and devices are available. Shading methods can either be fixed or adjustable.

External Devices: These are 30% more effective than internal shading devices because they prevent solar radiation from reaching the building's interior. Shading devices can take the form of vertical or horizontal projections or they can be a part of the building structure.

They can be either fixed or movable. Movable louvers and screens have the advantage of increased user comfort. They can protect or shade windows from radiation during overheated portions of the day and year without preventing "useful" radiation in under-heated times.

Horizontal Devices : These are efficient where there is a need to minimize radiant heat gain in the overheated period and to maximize it in the underheated period. Horizontal shading devices depend primarily on the sun's altitude :

Shadow = (Depth of overhang) x (Sin Θ). Horizontal shading is best used on south facing walls and is less effective on east and west facing walls because of the sun's lower altitude in the early morning and late evening.

Vertical Devices : These are generally more efficient when located on east and west facing surfaces. Combinations of vertical and horizontal elements can be used effectively to control solar radiation if the proportions are carefully related to sun angles during the critical times of the day.

Internal Devices : Although these devices are less efficient than external devices, their efficiency can be increased with the use of lighter colours, due to the reflective properties. An advantage of the internal shading devices is that people inside the building can control these, as required. Interior shades also can be used to reduce building heat loss in underheated periods. Blinds are most effective in reducing solar heat gain when they are used in combination with clear glass. Roller shades also are very effective through clear glass but have the disadvantage of eliminating outward vision when drawn. A white, opaque roller shade will reduce heat gain through clear glass by 75%. The ability of draperies to reduce heat gain depends on both the texture of the weave and the reflective properties of the materials from which they are woven. Light coloured draperies made from a tightly woven fabric will reduce heat gain through clear glass by 63%.

Fenestration

Air moves naturally in and out of a building as a result of pressure and temperature differences. The tendency of air is to equalize the high and low pressures created by the wind flow around the buildings. This difference in pressure force can be used to naturally ventilate a building. Pressure difference also cause infiltration and exfiltration. Inside a building further pressure

differences are created by temperature differences. Warm, less dense air rises through building or space and tends to draw in air at lower levels. This is called "stack" or "chimney" effect. The combination of these two factors - external pressure differences caused by wind flow and internal pressure difference caused by chimney effect - combine to influence airflow patterns in and out of the building. A high surface-to-volume ratio with maximum exposures to the wind can maximize pressure for natural ventilation. By minimizing the surface-to-volume ratio, a designer can protect a building from the effects of infiltration and exfiltration. Building shape can also increase the low-pressure areas. In low-rise buildings, thermal forces are rarely sufficient to create air movement for thermal comfort in overheated periods.

Openings/Windows

Location : For effective airflow, a space must have an inlet in a high pressure area, and an outlet in a low pressure area. There are four generic types of flow :

* Flow directly through the building;
* Flow through adjacent walls;
* Flow through a space with inlet and outlet of the same size;
* Flow through a space to the roof.

All of these types require high and low pressure areas in the appropriate places. They thus require exposure to the direction of the prevailing wind. Some of the examples are illustrated in the figure 17.

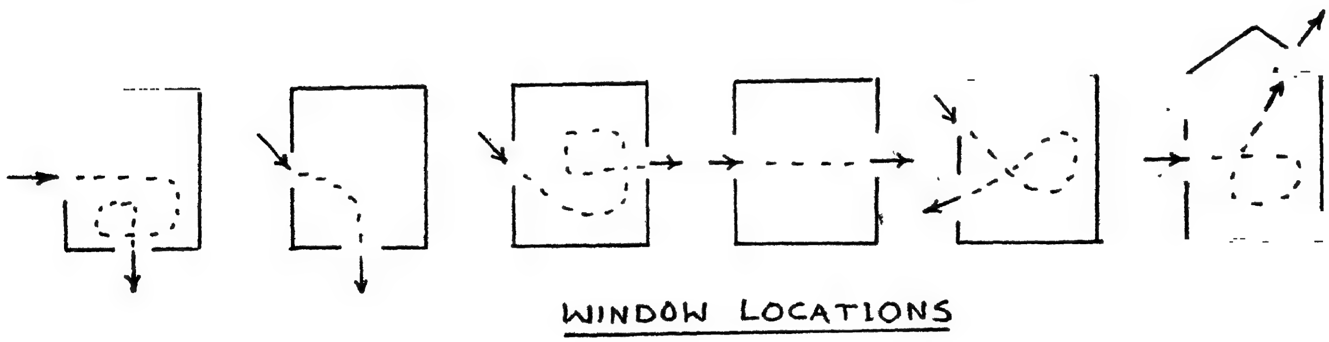


Figure 17

Placement : The placement, size and type of windows are critical in order to optimize natural ventilation. The vertical placement of the inlet has a major effect on the direction of flow of air through a space. The placement of an inlet, high on the wall diverts airflow upward, decreasing cooling effect. The placement of an inlet a few metres off the floor

results in an ideal pattern. The placement of the outlet-high, middle or low on a wall has no effect on air flow patterns. Again, it is primarily the inlet which determines the distribution of air.

Size : In order to maximize velocities, the outlet should be larger than the inlet. If there are two outlets, it does not mean that there will be dual flow.

Types : Different types of inlet windows affect the volume and the distribution of air through a space. Most windows tend to keep air at a horizontal level or to direct air upward rather than in the downward pattern usually necessary for good ventilation. Vents can be used with the same effect as windows, or in combination with windows. Using the same principles that apply to windows, the designer should note whether the vents will deflect air upward, keep airflow horizontal, or direct air downward.

Interior planning and auxiliary comfort devices are also equally important design consideration factors, to effect comfort conditions.

Building Metabolism

Load Factors

To demonstrate how heat gains and losses vary throughout yearly building operation, consider the Load Factor chart below (figure 18) which shows some of the possible combinations of factors that contribute heat flow and which influence building heat gains and losses at different periods of the year. The number of possible variations is obviously much greater than the common ones listed.

COMBINATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SUMMER	•	•	•	•	•	•	•	•								
WINTER									•	•	•	•	•	•	•	•
DAY SOLAR	•	•		•					•	•		•				
NO SOLAR			•		•						•		•			
NIGHT						•	•	•						•	•	•
OCCUPIED	•	•	•			•			•	•	•			•		
UNOCCUPIED				•	•		•	•				•	•		•	•
LIGHTS ON	•		•			•	•		•		•			•	•	
LIGHTS OFF		•		•	•			•		•		•	•			•

Figure 18

By examining the load factor chart, one can know those combinations which require cooling and heating. One can also find a number of combinations that are variable in their need for cooling or heating, depending on the relationship of the factors in each combination at any given point in time.

1. Load-factor combinations Nos. 1 through 8 are all net heat gains; that is net cooling loads.

2. Load-factor combinations Nos. 13 and 16 are net heat losses; that is, net heating loads.

3. Load factor combinations Nos. 9 through 12 and Nos. 14 and 15 may be net heat gains (net cooling loads) or net heat losses (net heating loads), depending on the magnitude of each load component at a particular point in time during cold weather periods.

During hot weather, the external thermal stresses will cause the building to have a net internal heat gain, producing a net cooling load. Under all other cold weather circumstances, the building may have either net heat losses (net heating loads) or net heat gains (net cooling loads). During intermediate temperature seasons, all combinations of load factors may be either net heat losses (net heating loads) or net heat gains (net cooling loads), depending on the magnitude of each load component at a given point in time.

Comfort

Comfort within a building can be of two types - thermal comfort and visual comfort.

Thermal Comfort

The following factors come into play while designing for thermal comfort :

1. Human Needs - Objective here should be to make the internal climate less variable than the external one.

2. Comfort zone - is defined as that range of effective temperatures over which 50% of people feel comfortable, namely 17°C effective temperature to 21°C effective temperature. Psychometric charts with temperature as abseissa and absolute humidity as ordinate, help to read directly such characteristics as relative humidity, wet bulb temperature and latent heat of vapourization as indicated by lines on the chart.

3. Radiation - Accommodating radiation can also have an impact on the range in which one feels comfortable.

4. Humidity - It is concluded that there is significant reduction in respiratory disease when there is an increase in relative humidity. Aerobiology research has noted that there is a general decrease in the life of airborne micro organism as the humidity in the air is increased.

5. Air Velocity - A range of 7 m.p.m. in the occupied zone of a room will eliminate stuffiness without significantly affecting the effective temperature felt by the individual.

6. Ventilation - Can be defined as the introduction of air without necessarily controlling its humidity, cleanliness or temperature. To maintain comfort in enclosed spaces, air changes are needed to disperse carbon dioxide, organic vapours, heat and moisture produced by people and their activities. Tobacco smoke is a severe air contaminant which requires as much as 10 times the ventilation required for non smoking areas.

7. Human Activities - Requirements for the thermal comfort range, change with the level of physical activity of the occupants. Cooler space temperatures should be provided for people engaged in strenuous activities such as sports, etc.

8. Clothing - Finally the amount of weight of clothing a person wears, his activity, age and health, can have a considerable perception of thermal comfort.

Visual comfort

The field of human vision ranges 60 degrees upward, 70 degrees downward and 180 degrees horizontally.

Foveal vision - is the acute perception of detail and exists as a central visual field area of no more than 2 degrees in diameter. Whereas, Peripheral vision - is the area of the visual field outside of the foveal vision area. As the field becomes more peripheral, images are perceived less distinctly and the eyes respond more to movement, pattern and intensity. While foveal vision is used for performance of visual tasks, peripheral vision is most important to the sense of space and general orientation. Visual comfort, therefore, can be defined as a fulfillment and requirements related to the definement of space and the performance of visual tasks.

Illumination

Illumination as an energy conscious design issue parallels the problems and objectives of thermal design. In both cases, responsive building design that takes advantage of the natural environment can provide comfort without relying entirely on artificial systems. Daylighting technology has advanced to the point that natural light in a building can be enhanced greatly by sensitive design. Both the quantity and quality of light can be controlled. The programmatic requirements for light, as well as the availability of light must be carefully evaluated, as well as window size, position, shape, controls and its relation to the room, the building and the environment. Artificial light can be considered a supplement to natural illumination, designed to provide visual comfort where or when daylight is insufficient.

Location

Daylighting is a function of the size, shape, location and materials of windows and other openings in the building's opaque envelope. Factors which determine the amount of natural light received by a building include : direct sunlight, clear sky illumination, cloudy sky illumination and ground reflection.

Direct Sunlight : Is rarely useful for direct task illumination because it can result in excessive glare.

Clear Sky Illumination : Is more useful because it is diffuse and of moderate intensity. The amount of illumination available on a clear sky and the time when it is available is dependent on the orientation of the building surfaces and windows.

Cloudy Sky Illumination : Differs from clear sky conditions because orientation is no longer an important factor. On clear days, the sky is brighter near the horizon than overhead, while the reverse is true on overcast days.

Ground Reflection : From adjacent surfaces is not as significant as sky illumination. The relation of openings to reflective surfaces can increase illumination or provide illumination to otherwise unlighted areas.

Form

Surface/Volume Ratio : While the thermal requirements of a building call for a low surface to volume ratio, the need for natural illumination is just the opposite. The more perimeter area, the better the opportunity to admit daylight.

Glazing : The distribution of glazing in a room is of major importance in achieving effective natural lighting. The window manipulations which affect the daylight factors in a room are :

* Placement of glazing;
* Glazing area/floor area;
* Room dimensions (height and depth); and
* Window devices (exterior and interior).

These are only a few of the issues illumination design addresses, but they make clear the point that illumination is both a conceptual, often intuitive, and a hardware problem. Daylighting, as seen above, is stressed as a function of location and form of the building, while artificial lighting as an element of the building's metabolic system's design.

NATURAL COOLING
IRANIAN CONTRIBUTIONS

Concepts and Principles

Arid regions are characterized by very low annual rainfall, low relative humidity, a high degree of solar radiation and hot days, a high rate of radiation loss to the sky during the night, and rather fixed patterns of diurnal and seasonal winds. People who have lived in these regions, adopted a way of life, highly influenced by the climate. For example, they have accommodated their dwellings to the climate in the following ways :

1. Reduced the exposed surfaces of the buildings and the heat transfer with the outside air by constructing buildings attached to each other with common walls, in a cluster form.

2. Made use of the high daily temperature range in summer and employed thick adobe walls and a small number of doors and windows for their rooms. By means of the latter they also reduced the energy exchange with the outside air, as well as the infiltration and collection of dust in the building.

3. Made use of the radiation losses to the sky by producing ice in winter and storing it for summer, and sleeping in the open air, mostly on the roof, during the summer nights.

4. Built large, deep cisterns, filled them with cold water in winter, and kept them cool through the summer by providing a continuous and natural evaporation of water from their surfaces.

5. Reduced solar heat gain on the walls by building deep courtyards surrounded by rooms, planting trees and shrubs in them, and entrapping the cool night air for several hours of the next morning. They further reduced the effects of dusty winds by employing tall parapets, which also provided the privacy needed for summer night use of the roofs. The tall walls and the narrow streets provided good shade for pedestrians and reduced solar heat gain.

6. Made use of the prevailing summer winds, developed wind towers, and created excellent natural circulation and cooling of the outside air through the building.

7. Made use of the low temperature of the ground in summer and lived in the basements, especially in the summer afternoons.

8. Employed dome-type roofs for many rooms, especially the kitchen, in order to increase the heat transfer coefficient and area, to create a suction on top of the dome, and to vent the hot air underneath the dome. In locations where dusty winds predominate, one finds these natural air vents, instead of wind towers, employed for air circulation.

9. Used solar energy in the rooms designed for winter occupancy, and stored the energy in the heavy walls and roofs of the building.

10. Did not heat all the rooms in winter, but only those that were utilized and even then only at the time of occupancy.

Wind Towers

Wind towers in Iran are masonry structures designed to provide natural circulation and cooling of the ambient air through the building. The openings on top of the tower may face in all directions or only in the direction from which the wind is predominant.

Night Operation : When there is no wind blowing at night, the wind tower acts as a chimney. The tower walls that have been heated during the day transfer heat to the cool night ambient air. The heated air is then exhausted at the openings. This chimney action of the tower maintains a circulation of the ambient air through the building and cools the structure of the building as well as that of the wind tower. When wind is blowing during the night, the air circulation is in the direction opposite to that described, but the walls of the tower are cooled, and some cooling of the rooms may also result.

Day Operation : When there is no wind blowing during the day, the tower operates as the reverse of a chimney. The hot outside air in contact with cold walls (cooled during the previous night) is cooled and sucked in through the passages. This air may then be let out through the door. When there is wind, the air circulation and the rate of cooling are increased, and the cold air can reach far distances.

Note : It is clear that wind towers, in addition to not requiring active energy, are in many cases more effective than evaporative or desert coolers (which have become very popular in Iran recently).

Design : There are numerous wind tower designs. They include various tower heights and openings, and different cross sections for the airflow passages. All of the designs attempt to provide desired airflow rate, heat transfer area, sensible heat storage capacity, and evaporative cooling surfaces. Wind towers are for summer use only. If not closed properly in winter, they can increase the infiltration heat losses appreciably.

Cisterns

Energy storage from one season to another is an excellent method of passive cooling or heating. As arid zones are characterized among other things by their very cold nights and since earth provides good insulation, people stored cold water or fabricated the ice in winter for summer use. Cold water was stored in cisterns 10-20 m deep and were filled during the cold winter nights. To keep this water cold for summer use, a natural evaporation of the water surface was provided by the draft produced by several wind towers.

When there was an opening at the apex, air flew down through the tower and out through an opening, entraining with it the saturated air that existed under the dome. When no hole was provided in the apex of the dome (to prevent birds and dirt from falling in) the air passage in the wind towers was short-circuited, with air entering at the windward, entraining some of the air over the water surface, and then leaving at the leeward openings.

CHOOSING THE SYSTEM

Each system has specific design limitations and use. That system must be chosen, which satisfies most of the design criteria in relation to its thermal needs and availability of space. The following is a general assessment of the characteristics displayed by the respective system :

1. DIRECT GAIN SYSTEM

Building Form : The building is usually oriented along the east-west axis, with spaces needing heat located along the south wall.

Glazing : The major glass area must be oriented towards the south and it is essential that windows be carefully designed to eliminate the problem of glare often associated with direct gain systems.

Materials : The system generally implies a heavy building in the interior wall and floors constructed of masonry materials.

Thermal Control : Direct gain systems are characterized by daily indoor fluctuations. To prevent over-heating, shading devices are used to reduce solar gain, or excess heat is vented out by opening windows/vents.

System Efficiency : When properly designed, a direct gain system is roughly 30 to 75% efficient in winter.

Retrofitting : Retrofitting an existing building with a direct gain system is somewhat difficult, since the building by itself is the system.

Conclusion : This system demands a skillful and total integration of all architectural elements within each space - windows, walls, floor, roof and interior surface finishes. A direct gain system can usually be built for the same cost as a conventional masonry building.

2. INDIRECT GAIN SYSTEM (Thermal Storage Wall)

Buildin Form : The depth of a space is limited to app. 5 to 6 metres, since this is considered the maximum distance for effective radiant heating from a solar wall.

Glazing : The south-facing glass functions as a collecting surface only and admits no natural light into the space.

Materials : Either water or masonry can be used for a thermal mass wall. Double glazing in front of the wall is necessary unless insulating shutters are applied over the glazing at night.

Thermal Control : Indoor temperature fluctuations are controlled by wall thickness. The heat output of a masonry wall can be regulated by the addition of thermo-circulation vents with operable dampers or by movable insulating panels or drapes placed over the inside face of the wall.

System Efficiency : The overall efficiency of the system is app. 30 to 45%. For the same area of wall and heat storage capacity, a water wall will be slightly more efficient than a masonry wall.

Retrofitting : This system can be added without much difficulty to the south wall of a building.

Conclusion : The system allows for a wide choice of construction materials (exclusive of the thermal wall) and interior finishes, and offers a high degree of control over the indoor thermal environment.

3. ATTACHED GREENHOUSE SYSTEM

Building Form : The greenhouse must extend along the south face of the building adjoining the spaces to be heated.

Glazing : To heat one square metre of building floor area (excluding the greenhouse) app. $1\frac{1}{2}$ times as much greenhouse glass area is needed.

<u>Materials</u> : The major construction material in the greenhouse is double glass or transparent plastic and the common wall (thermal mass-masonry or water) greenhouse and building.

<u>Thermal Control</u> : Temperature control in adjoining spaces is the same as for a thermal wall storage system.

<u>System Efficiency</u> : The overall efficiency of the system is app. 60 to 75% during the winter months. The percentage of heat supplied to adjoining spaces is roughly 10 to 30% of the energy incident on the collector face.

Retrofittin: : Retrofitting can be carried out easily by adding a south wall to an existing building.

<u>Conclusion</u> : The unique feature of the system is that it only produces fresh food but has the potential to heat itself and spaces adjoining it.

4. <u>ROOF POND SYSTEM</u>

<u>Building Form</u> : Since the roof itself is a collector, this system is most suitable for heating or cooling one-storey buildings, or the upper floor of a two-or more storey structure. The roof area containing the ponds can be flat, stepped up to the north or pitched.

<u>Glazing</u> : For summer cooling, the pond must be exposed to as much of the night skydome as possible.

<u>Materials</u> : Roof ponds are generally 15-30 cm in depth. A structural metal deck, which also acts as a finished ceiling and radiating surface is the most commonly used support for the ponds themselves.

<u>Thermal Control</u> : Roof pond heating and cooling is characterized by stable indoor temperatures and high levels of comfort due to large area of radiative surface.

<u>System Efficiency</u> : Roof ponds which are double-glazed (usually with an inflated plastic air cell) range in efficiency from 30 to 45%. It should be noted that the effectiveness of the seal made by the movable insulation will have an impact on the efficiency of the system.

Retrofitting : The requirements of a large area of radiating surface plus structural and modular considerations make it difficult to apply to existing structures.

Conclusions : Solar roof ponds are an inexpensive and effective method of providing both heating at lower latitudes and cooling in dry climates with clear night skies.

THUMBRULES

1. Wall Thickness

The best thickness of a Trombe wall is from 30 cm to 45 cm. The masonry should have a high density - at least 1600 kg/m^3.

2. Glass Area

Half a meter squared of south facing double glazing should be used for each W/°C of additional thermal load (i.e., exclusive of the glazing). This will give 70% to 80% solar heating at latitudes around 35°, for a building kept within the range of 18°C to 24°C.

3. Thermal Storage

A thermal storage capacity of at least 150 kg of water, or 5 times weight of masonry or rock should be used for each square metre of south facing glass. This storage should be located in the direct sun. If it is not located in the sun, four times more storage is needed.

4. Seasonal Adjustments

Shading of south glazing should be used to reduce summer and autumn over heating. An effective geometry is a roof overhang which will just shade the top of the glazing at a noon sun elevation of 45° and will fully shade the glazing at a noon sun elevation of 80°. If it is not possible to do this for the entire glazing, it is absolutely imperative for the windows in the wall behind the glazing. For heat wave periods, openable vents can be provided in the double glazing which discharge the hot air outside. The area is to be a minimum of five percent of the glazing spread over the entire length.

5. Daily Adjustments

Thermocirculation vents can be used to increase daytime heating but will not increase night time minimums. Vents should have lightweight passive back draft dampers or other means of preventing reverse flow at night. The area of vents depends upon the area of the glazing as well as the room height and plan ratio. Upper and lower vents should each be one percent of the glazing area and uniformly distributed over the E-W length of the south facing wall.

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GLOSSARY

Absorptance - The ratio of absorbed to incident solar radiation.

Adobe - A sun-dried, unburned brick of clay (earth) and straw used in construction.

Absorptivity - The capacity of material to absorb radiant energy. Absorbtance is the ratio of the radiant energy absorbed by a body to that incident on it.

Air Changes - Expression of ventilation rate in terms of room or building volume. Usually air changes/hour.

Air Conditioning - The process of treating air so as to control simultaneously its temperature, humidity, cleanliness and distribution to meet requirements of the conditioned space.

Air Mass - The path length of solar radiation through the earth's atmosphere considering the vertical path at sea level as unity.

Albedo - The ratio of the amount of light reflected by a surface to the light falling on it.

Altitude, Solar - The angle of the sun above the horizon.

Ambient Temperature - The natural temperature surrounding an object. It usually refers to outdoor temperature although it can, under some circumstances, mean an inside temperature.

Aspect Ratio - The ratio of the width to the length of a building plan.

Auxiliary System - A supplementary system utilized when the primary system cannot perform full work load adequately.

Azimuth, Solar - The horizontal angle between the sun and due south. Also known as bearing angle.

Berm - A man-made mound or small hill of earth.

Bio-Climatic Approach - Methodology of a design which effectively responds to the local climatic elements to provide for human comfort needs. The approach was espoused by Victor Olgyay in "Design with Climate."

Black Body - A body that absorbs all incident radiation and reflects or transmit none. Additionally, a black body is a perfect radiator, i.e., it emits or radiates the maximum amount of radiant energy for any surface at any given temperature.

Building Envelope - The elements of a building (e.g. walls, roofs, floors) which enclose conditioned spaces through which thermal energy may be transferred to or from the exterior.

Calorie - A unit of heat energy equal to the amount of heat that will raise the temperature of one gram of water 1 degree Centigrade. The calorie is used when temperature is measured on the Centigrade scale, while the British thermal unit is used when the measurement is on the Fahrenheit scale. One calorie equals 3.97×10^{3} Btu, 4.18 joules, and 1.10×10^{3} watt hours.

Clearness Factor - The ratio between the actual clear-day direct solar radiation intensity at a specific location and the intensity calculated for the standard atmosphere for the same location and date.

Climatological Design Conditions - Selected outdoor conditions which predict the maximum and minimum temperatures to which a building will be subjected. Also outdoor temperature conditions selected to maintain occupants' comfort.

Cloud Cover - Amount of cloudiness normally expressed in tenths of a full overcast sky.

Coefficient of Performance - The ratio of heating or refrigeration system effect to the rate of energy input, in consistent units, under designated operating conditions.

Coefficient of Utilization - Ratio of lumens on a work plane to lumens emitted by the lamps.

Colour Rendering Index - The measure of the degree to which the perceived colours of objects illuminated by the source conform to those of the same objects illuminated by a reference source for specified conditions.

Comfort Zone - (Average): the range of effective temperatures over which the majority (50% or more) of adults feels comfortable; (extreme): the range of effective temperatures over which one or more adults feel comfortable.

Condensation - The production of moisture which results when warm, moist air comes in contact with a colder surface and deposits moisture onto that surface. The resulting water is called condensate.

Conductance, Thermal - A measure of the thermal conducting properties of a single material.

Conduction - The method whereby heat is transferred from one body to another without physical displacement of the matter within the bodies.

Convection - The transfer of heat by movement of a fluid (gas, vapor, or liquid).

Convection, Forced - Convection resulting from circulation of a fluid by a fan or pump.

Convection, Natural - Circulation of a gas, vapor or liquid medium (usually air or water) due to differences in density resulting from temperature changes.

Cooling Load - The rate at which heat must be removed from a space to maintain room air temperature at the constant value which was assumed when calculating heat gain. (The cooling load differs from heat gain in that the radiant part does not immediately appear as the cooling load but is absorbed by surfaces that enclose the space. When these surfaces become warmer than the indoor air, heat is transferred to the air by convection).

Coolth - A moderate degree of coolness (antonym for warmth).

Damper - A device used to vary the volume of air passing through an air outlet, inlet or duct.

Daylight Factor - A measure of daylight illumination at a point on a given plane expressed as a ratio of the illumination on the given plane at that point to the simultaneous exterior illumination on a horizontal plane from the whole of an unobstructed sky of assumed or known luminance (photomeric brightness) distribution. Direct sunlight is excluded from both interior and exterior values of illumination.

Daylighting - The use of controlled natural lighting methods indoors through toplighting (skylights), sidelighting (windows), and/or uplighting (reflection).

Declination, Solar - The angle of the sun north or south of the equatorial plane. It is plus if north of the plane and minus if south.

Degree Day, Heating - A unit measurement based on temperature difference and time, used in estimating average heating requirements for a building. For any one day, when the mean outside temperature is less than 18 degrees C, there exist as many degree days as there are Centigrade degrees difference in temperature between the mean temperature and the base temperature 18 degrees C. This base temperature assumes that no heat input is required to maintain the inside temperature at 21 degrees C when the outside temperature is 18 degrees C.

Dehumidification - The condensation of water vapor from air by cooling below the dewpoint or removal of water vapor from air by chemical or physical methods.

Design Outside Temperature - The outdoor temperature used in the calculation of the heating load. This temperature is derived by statistical methods and is not necessarily the lowest temperature ever recorded for a given locality.

Disability Glare - Spurious light from any source, which impairs a viewer's ability to discern a given object.

Diurnal Temperature Range - The range of temperature occuring over a 24-hour time span.

Dry Bulb Temperature (D.B.T.) - The measure of the sensible temperature of air.

Efficiency, Thermal - Relating to heat, a percentage indicating the available input converted to useful purposes. The term is generally applied to combustion equipment.

Emittance - Is a rating of the ability of a material to give off heat as radiant energy. It is equal to the amount of heat absorbed (absorptance), so the sum of emittance and reflectance, expressed as percent, is 100%. The same ratio applied to opaque and optically flat surfaces is called Emissivity; for ordinary materials, emittance is preferred.

Emissivity, Thermal - The capacity of material to emit radiant energy. Emittance is the ratio of the total radiant energy emitted by a body to that emitted by a black body at the same temperature. Note : The emissivity of a surface is numerically equal to its absorptivity when the radiating source is a black body at the same temperature as the surface.

Energy - The capacity for doing work. Different forms may be transformed from one type into another, such as thermal (heat), mechanical (work), electrical, and chemical. Energy is measured conventionally in kilowatt-hours (kwh) or British thermal units (btu). Energy is measured in S1 units in joules (j) where 1 joule = 1 watt-second.

Energy Budget - A design or consumption budget for a building or space use which is expressed in energy units that reflect the energy used to operate the various service systems. (Budget figures may also include the nature of the energy source, including conversion, transportation and distribution losses).

Energy, Net - The energy remaining after the energy costs of extracting, concentrating, and distribution are substracted from the initial source.

Enthalpy - Thermodynamic property of a substance defined as the sun of its internal energy plus the quantity Pv/J, where P = pressure of the substance, v = volume of substance, and J = the mechanical equivalent of heat.

Entropy - The ratio of the heat added to a substance to the absolute temperature at which it is added.

Equivalent Sphere Illumination - That illumination which would fall upon a task covered by an imaginary transparent hemisphere which passes light of the same intensity through each unit area.

Evaporative Cooling - The adiabatic exchange of heat between air and a water spray of wetted surface. The water approaches the wet-bulb temperature of the air, which remains constant during its traverse of the exchange.

Enfiltration - Indoor air leakage to the exterior through building envelope caused by a pressure differential.

"Flywheel Effect" - The damping of exterior temperature extremes inside buildings of heavy construction due to inertia of heat movement or storage.

Flux - A form of radiation energy measured in units of lumens.

Glazing - A covering of transparent or translucent material (glass or plastic) used for admitting light. Glazing retards heat losses from reradiation and convection. Examples: windows, skylights, greenhouse and collector coverings.

Gravity Ventilator - A roof depending for its operation on the natural upward draft of the less dense air from within the building.

Heat Capacity - The quantity of heat required to raise the temperature of a given mass of a substance one degree.

Heat Gain - As applied to HVAC calculations, it is that amount of heat gained by a space from all sources, including people, lights, machines, sunshine, etc. The total heat gain represents the amount of heat that must be removed from a space to maintain desired indoor conditions.

Heat Lag - Resulting time delay of heat transfer through material due to heat capacity and thermal resistance.

Heat Loss - The sum cooling effect of the building structure when the outdoor temperature is lower than the desired indoor temperature. It represents the amount of heat that must be provided to a space to maintain indoor comfort conditions.

Heat Recovery - Heat utilized which would otherwise be wasted.

Heat Sink - A body (water, earth, metal, etc.) capable of accepting and storing heat. It can also serve as a heat source.

Heat Transfer - The methods by which heat may be propagated or conveyed from one place to another. This may be by conduction, convection or radiation.

Heat Transmission Coefficient - Any one of a number of coefficients used in the calculation of heat transmission by conduction, convection, and radiation, through various materials and structures.

Heliodon - A device used to simulate the effect that the sun's position has on models of buildings and other objects. Primarily used to conduct shadowing studies.

Humidity, Relative - The ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature.

Illumination - The density of the luminous flux incident on a surface.

Incident Angle - The angle between the sun's rays and a line perpendicular to the irradiated surface.

Infiltration - Outdoor air leakage into a building. It most often occurs at cracks around doors, windows and other openings.

Infrared - Thermal radiation or light with wavelengths longer than 0.7 microns. Invisible to the naked eye, the heat radiated by objects at less than 538 degrees Centigrade is almost entirely infrared radiation.

Insolation - The solar radiation incident at the earth's surface.

Insulation - A material having a relatively high resistance to heat flow and used principally to retard the flow of heat. Four major classifications of building insulating materials are : (1) batt, (2) loose fill, (3) reflective, and (4) rigid.

Kilowatt (kw) - A unit of power equal to 1,000 watts or to energy consumption at a rate of 1,000 joules per second. It is usually used for electrical power. An electric motor rated at 1 horsepower uses electrical energy at a rate of about 3/4 kilowatt.

Langley - The meteorologist's unit of solar radiation intensity, equivalent to 1.0 gram calorie per square centimeter.

Latent Heat - The change in heat quantity that occurs without any corresponding change in temperature. Usually accompanied by a change of state; for example, water may change to steam, or the moisture content in air may be increased.

Load - Indicates a rate of flow of energy for either a heating or cooling requirement or a total of both.

Load Profile - Time distribution of building heating, cooling, and electrical load.

Luminance - The light flux emitted, reflected or transmitted from a surface or source and perceived as the brightness of that surface or source; footlamberts are the units of luminance.

Mean Radiant Temperature - If all surfaces in an environment were uniformly at this temperature, it would produce the same net radiant heat balance as the given environment with its various surface temperatures.

Microclimate - Climate at specific site as defined by local variations in the regional climate caused by topography, vegetation, soils, water conditions, as well as man-made construction.

Night Sky Radiation - Method of cooling through radiant energy exchange whereby relatively warm surfaces are exposed directly to the colder night sky.

Radiation - Energy in the form of electromagnetic waves which is continually emitted from the surface of all bodies.

Radiation, Incident - The quantity of radiant energy incident on a surface per unit time and unit area.

Radiation, Longwave - Radiant energy emitted from the sun in the wavelength range between 0.3 and 3.0 microns.

Radiation, Solar - Radiant energy emitted from the sun in the wavelength range between 0.3 and 3.0 microns. Of the total solar radiation reaching the earth, approximately 3% is in ultraviolet region, 44% in the visible region, 54% in the infrared region. Radiant energy may be expressed as (1) diffuse - solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere, or as (2) direct beam - solar radiation received from the sun without undergoing a change of direction.

Radiation, Visible - Radiant energy of wavelengths from 0.4 to 0.76 microns which produces a sensation defined as "seeing" when it strikes the retina of the human eye.

Reflectivity - The capacity of a material to reflect radiant energy. Reflectance is the ratio of the radiant energy reflected from a body to that incident on it.

Resistance, Thermal - The reciprocal of thermal conductance.

R-Value - The thermal resistance of a material or structure, equal to 1/U.

Sensible Heat - Heat that results in a change in temperature (as opposed to latent heat) and that can be "sensed", or felt.

Shading Coefficient - The ratio of the solar heat gain through a glazing system corrected for external and internal shading to the solar gain through an unshaded single light of double strength sheet glass under the same set of conditions.

Skytherm System - A form of movable insulation and a roof pond system developed by Harold Hay. The system involves motor-driven sliding insulation ponds.

Sol-Air Temperature - The theoretical air temperature that would give a heat flow rate through a building surface equal in magnitude to that obtained by the addition of conduction and radiation effects.

Solar Constant - The amount of solar radiation incident on a unit area of surface located normal to the sun's rays outside the earth's atmosphere at the earth's mean distance from the sun.

Space Cooling - Cooling for the interior spaces of a building.

Space Heating - Heating for the interior spaces of a building.

Specific Heat - The amount of heat that has to be added to or taken from a unit of weight of a material to produce a change of one degree

Stratification - The existence of persistent temperature gradients in a fluid.

Sun Time - A time related directly and exclusively to the position of the sun. For example, noon occurs when the sun is due south. There are variations in different longitudes.

Temperature - A measure of heat intensity or the ability of a body to transmit heat to a cooler body.

Therm - A quantity of heat.

Thermal Inertia - The property which modifies the effect of the U-value on the heat transmission of a building element by expanding the time scale and produces a time lag in heat transfer. Thermal inertia is beneficial when there is a cyclic temperature differential.

Thermodynamics, Laws Of - Two laws upon which rest the classical theory of thermodynamics. These laws have been stated in many different, but equivalent, ways. The First Law : (1) When work is expended in generating heat, the quantity of heat produced is proportional to the work expended; and conversely, when heat is employed in the performance of work, the quantity of heat which disappears is proportional to the work done (Joule); (2) If a system is caused to change from an initial state to a final state by adiabatic means only, the work done is the same for all adiabatic paths connecting the two states (Zemansky); (3) In any power cycle or refrigeration cycle the net heat absorbed by the working substance is exactly equal to the network done. The Second Law : (1) It is impossible for a self-acting machine, unaided by an external agency, to convey heat from a body of lower temperature (Clausius); (2) It is impossible to derive mechanical work from heat taken from a body unless there is available a body of lower temperature into which the residue not so used may be discharged (Kelvin); (3) It is impossible to construct an engine that, operating in a cycle, will produce no effect other than the extraction of heat from a reservoir and the performance of an equivalent amount of heat from a reservoir and the performance of a equivalent amount of work (Zemansky).

Time Lag - The delay caused by thermal inertia and heat storage in a building element (such as a wall) and its subsequent release by the structure. As the mass of the element increases, the time lag increases.

Ton of Refrigeration - One ton of refrigeration means the removal of heat at the rate of 3,000 Kcals per hour.

Transmission, Thermal - The rate at which heat passes through a material and is directly proportional to the U value and the temperature differential across the material.

Transmissivity - The capacity of material to transmit radiant energy. Transmittance is the ratio of the radiant energy transmitted through a body to that incident on it.

Transmittance - The . . . .ted to energy incident on a surface. In solar technology it is often affected by the thickness and composition of the glass cover plates on a collector, and to a major extent by the angle of incidence O between the sun's rays and a line normal to the surface.

U-Value - The heat flow rate through a given construction assembly, air to air, expressed in Kcal/Hr. / m / degree difference between indoor and outdoor temperatures.

Veiling Reflections - Reflection of light from a task, or work surface, into the viewer's eyes.

Ventilation - The process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned.

Watt - The amount of work available from an electric current of 1 ampere at a potential of 1 volt. The watt is also the metric unit of power, and is equal to a rate of energy consumption of 1 joule per second.

Wet-Bulb Temperature (W. B. T.) - The lowest temperature attainable by evaporating water in the air without the addition or subtraction of energy (adiabatic saturation).

Zoning - The control of the temperature in one room or a group of rooms, independently from other rooms.